



EIOC 20th Year Anniversary Technology Showcase: Control Room of the Future Testbed Scoping

Eric Andersen
Host & EIOC Director

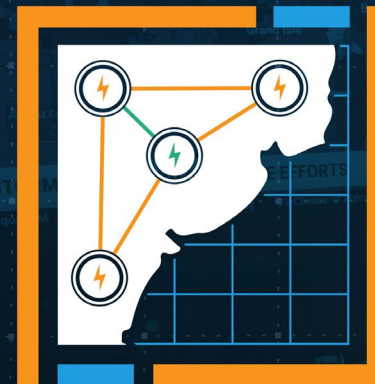


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Celebrating

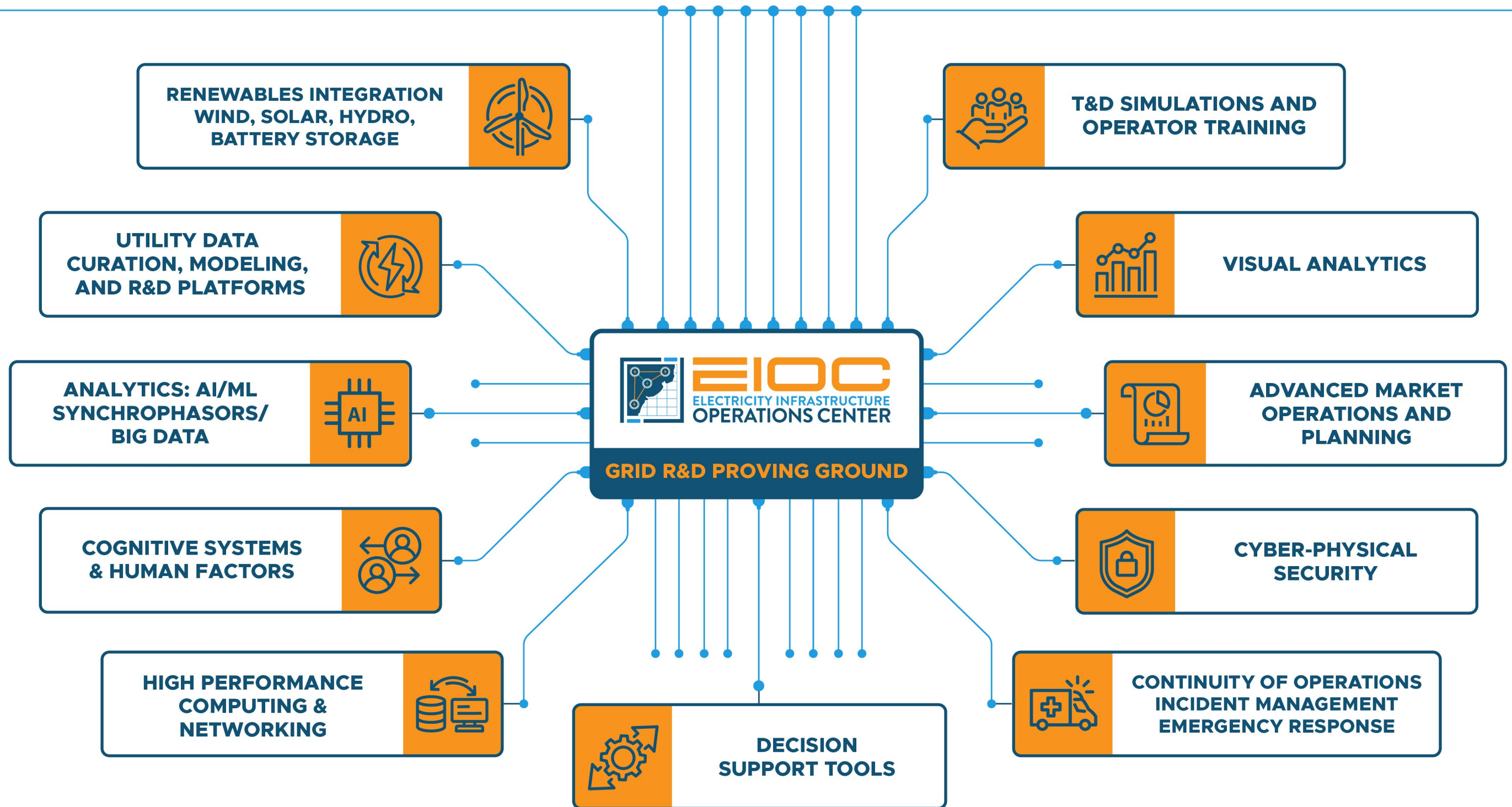


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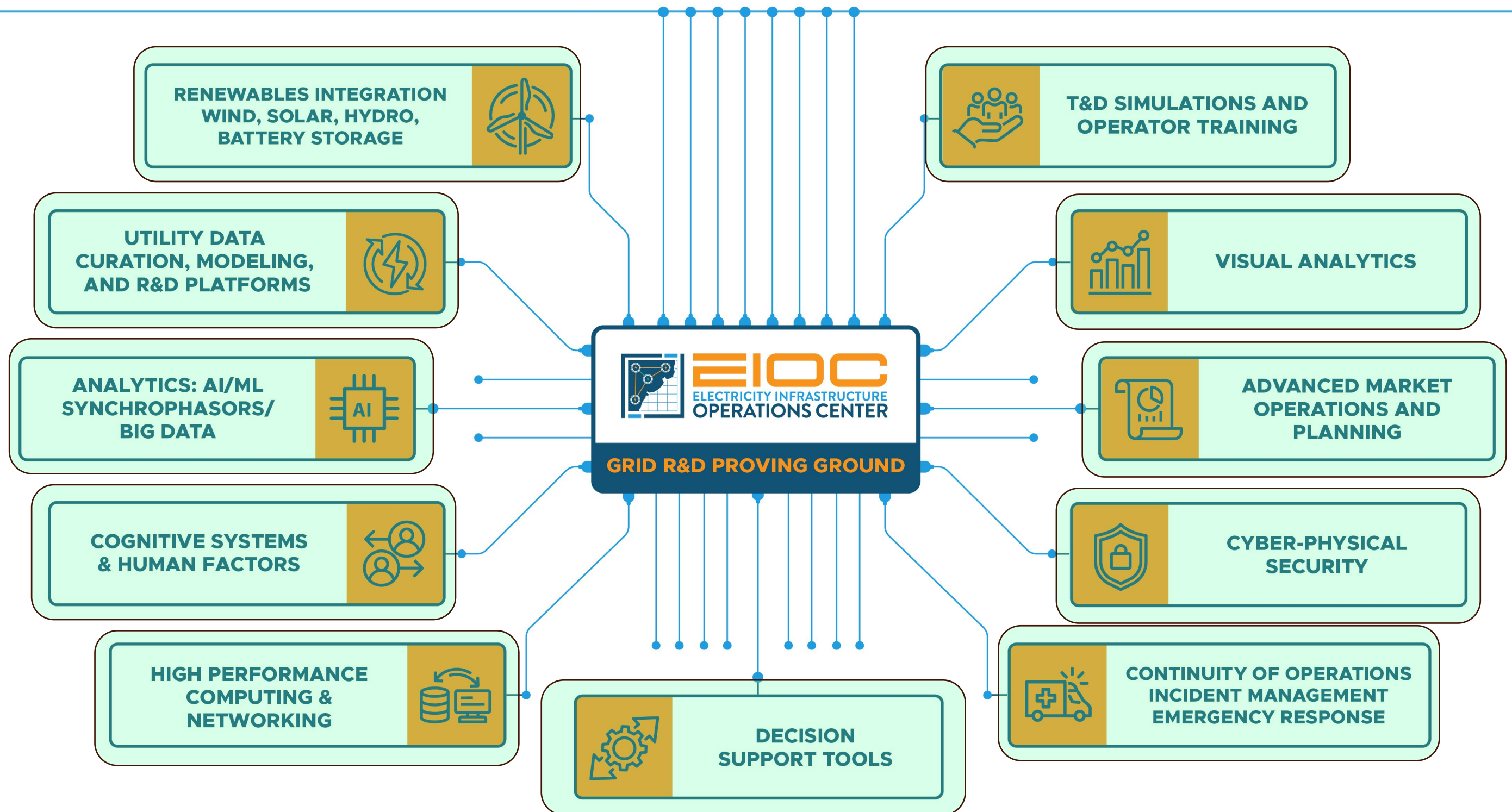
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20 Years!

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EIOC Technology Showcase

EIOC-Enabled Innovation



SCHEDULE

- **FEBRUARY:** EMS/ADMS T&D Co-sim (Hyder/Maharjan)
- **MARCH:** Grid Control Room Human factors (Fallon)
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- **OCTOBER:** Secure Communications (Larvick)
- **NOVEMBER:** TBD

Control Room of the Future Testbed

an assessment of
industry needs

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The Multi-Lab Team

- DOE-OE
- ANL
- INL
- NLR
- PNNL



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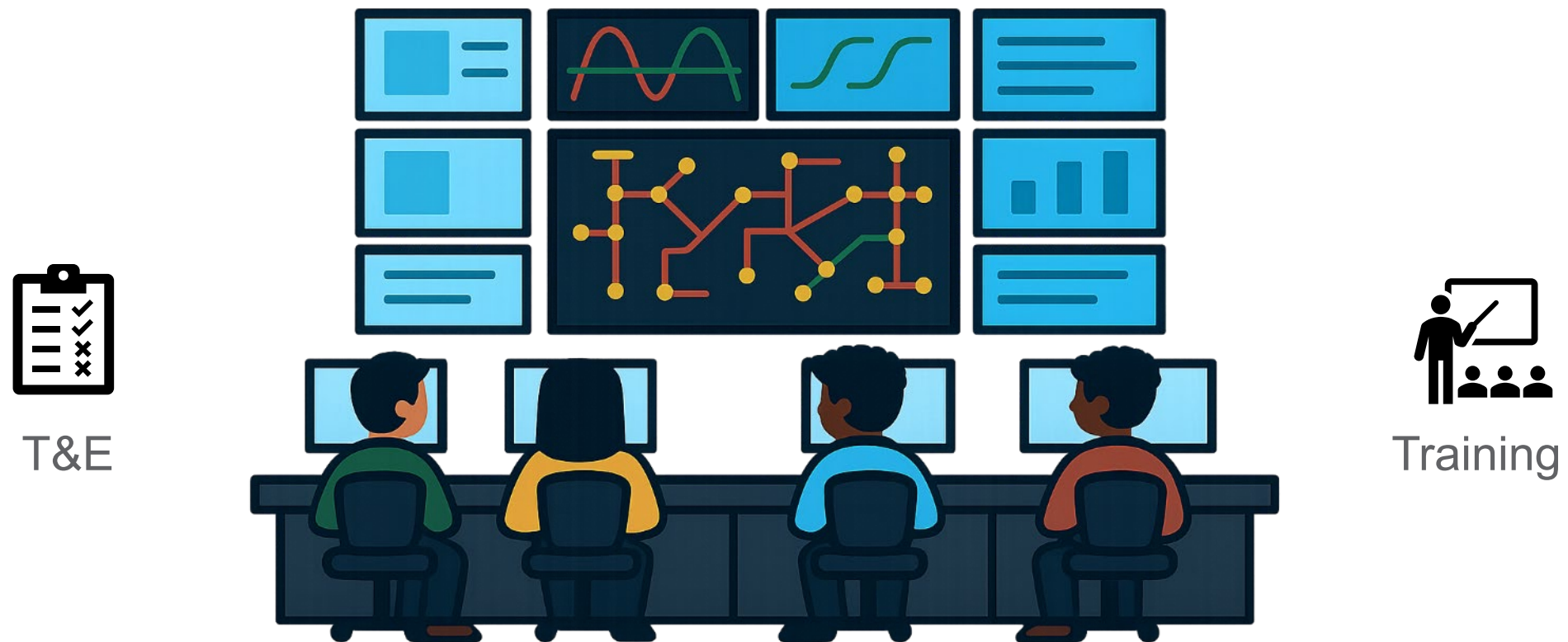
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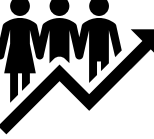
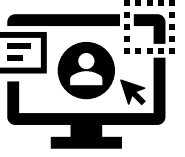


**National
Laboratory
of the Rockies**



Control Room of the Future Testbed



 Architectures  Approaches  Applications

Approach



Stakeholder Community

Electric Utilities | Product Developers | Consultants
Universities/Academia | National Laboratories | Other Organizations

Stakeholder Interviews Initial Outcomes (INL)

- Interview Approach
- Demographics
- Results
 - Top Grid Challenges
 - Top Use Cases
 - Top Validation Needs
 - Top Testbed Needs/Barriers
 - Top Insights
 - Implications for Test Bed Needs



Top Grid Operator Challenges

- Data Quality/Integration – siloed or incomplete data limits technology effectiveness
- Extreme Events/Resilience – severe weather and wildfire pushing infrastructure and operators to their limits
- Cognitive Load – Amount of data is ever increasing, overloading operators
- Trust in Automation/AI – lack of characterization of AI performance in operational environment limits confidence in AI
- Decision-Making (Time) – faster, higher-stakes decisions with little margin for error
- System Complexity – more distributed resources making the grid harder to manage

Top Testbed Use Cases

- Load Forecasting Including Large Loads – demand prediction complicated by data center growth
- Resource Optimization – balancing generation, storage, and transmission efficiently
- Decision Support– integration and data analytics to provide insight or recommendations to operators
- Grid Enhancing Technologies – need to be integrated into operations
- Outage Prediction – weather-informed analytics to enable outage prevention
- Training/Simulation – realistic environments to prepare operators for complex scenarios

Top Validation Gaps

- Data Realism – synthetic data alone is insufficient for reliable validation of new tools, technologies, approaches, and architectures
- Human in the Loop Testing – Operators are often not seen as part of the system, and engaged far too late in the development process; all validation should test the technology impact on human decision making
- Performance/Accuracy Thresholds – clear and measurable performance criteria are needed before deployment

Top Control Room Testbed Needs

- Data Fidelity and Variety – datasets must reflect real-world grid conditions
- System Integration – testbed must adequately represent end-to-end integration of existing systems and be both flexible and scalable
- Human in the Loop Capability – operators and dispatchers must be an integral part of the technology design/test/evaluate process in the role of the primary product end user
- Operational Realism – simulations and operator control room environments must replicate live grid complexity, including realistic workflows
- Safety & Risk Containment – testing must support and demonstrate that the technology will not introduce risk to grid stability when deployed to real, operational systems and assets on the grid
- Vendor Support – industry-grade products and vendor collaboration is needed to keep testbeds current and functional



Workshops

DistribuTech
Feb 2026
San Diego, CA



IEEE T&D
May 2026
Chicago, IL



- AI-emphasis



DistribuTech Workshop

- **Overview**

- Conducted February 5, 2026
- Multi-stakeholder participation Informec pre-workshop industry interviews
- Four national laboratories collaborating INL, NLR, PNNL, ANL

Organization Type	Number of Attendees
Electric Utilities	22
Vendors	5
Consultants	5
Universities	1
National laboratories	15
Federal Government	4
Total	52

DistribuTech Workshop

- **Workshop Approach**

- Elicited information from participants
 - ✓ Facilitated group discussions with participant voting
 - ✓ Reaction to preliminary interview findings
- Focus Areas
 - ✓ Eliciting operational challenges, use cases and implementation barriers
 - ✓ Prioritizing challenges, use cases and barriers through structured voting
 - ✓ Identifying current testing/validation practices and gaps
 - ✓ Prioritizing validation needs and testbed capabilities

DistribuTech Workshop

- **Key Workshop Findings**

- **Top Operational Challenges**

- ✓ Integration and interoperability of advanced systems (ADMS, DERMS)
- ✓ Information overload and cognitive burden on operators
- ✓ AI may offer high-value but must be trusted.

- **Major Implementation Barriers**

- ✓ Data quality issues and workforce constraints
- ✓ Lack of standardized testing and validation practices
- ✓ Limited operator involvement in validation and rare end-to-end testing

Implications and future directions

- The workshop identified several areas for continued research and collaboration
 - AI-enabled alarm management and actionable decision support,
 - Standardized validation frameworks
 - High-fidelity integration testing methodologies
 - AI-assisted data cleaning and model maintenance
 - Workforce transition strategies
 - Clarification of legal and regulatory considerations for AI-assisted operations.

Control Room of the Future Testbed Workshop

Workshop Date: **Monday, May 4, 2026**

- Goals
 - Inform future DOE research directions.
 - Identify high-impact opportunities for testbeds to bridge innovation and operations by enabling validation, de-risking, and rapid adoption of emerging technologies.
 - Explore how grid innovations, including emerging AI tools to support grid operations and operators, are redefining validation and testing paradigms, and the corresponding evolution needed in testbed infrastructure.
- Participating Organizations-**72 Participants**
 - Representatives from utilities (22), grid hardware and software vendors (9), power sector consultants (9), Universities (20), National Laboratories (20), and Federal Government (2).

Control Room of the Future Testbed Workshop

Topic A: Data Infrastructure Sharing, Access, and Requirements Findings

- **Multi-Rate Data & Interoperability:** Must transcend current application silos to simultaneously ingest diverse data formats (PSS/E, PSLF, CIM) and multi-resolution streams, ranging from standard SCADA to high-fidelity Point-on-Wave (PoW) data.
- **Data Diversity & Scale Challenges:** Requires a rich repository of real-world data types (OMS, GIS, logs, weather) including edge cases, while addressing the massive bandwidth, compute, and scalability constraints of large-scale AI/ML testing.
- **IT/OT Segmentation & Sandboxing:** Demands realistic replication of the IT/OT boundary with strict network segmentation, utilizing secure sandbox environments and unidirectional data flows to protect critical infrastructure during vendor and AI evaluation.
- **Data Governance & Synthetic Generation:** Resolves legal and privacy barriers to data sharing by integrating advanced anonymization, high-realism synthetic data generation, and configurable governance frameworks (role-based access, audit trails).

Control Room of the Future Testbed Workshop

Topic B: Benchmarking and Validating Performance Findings

- **Operational Latency & Efficiency:** Benchmarks must measure end-to-end response time (sense, decide, act) against incoming data rates, focusing on the human-AI team's ability to maintain efficiency and manage latency during dynamic load shifts and extreme grid events.
- **Operator Trust & System Transparency:** Trust cannot be evaluated without the operator; testbeds must assess both reliance and explainability. AI outputs—especially from LLMs—must provide clear traceability, auditability, and source attribution to counter over-confidence and build accountability.
- **Data Resilience & Adversarial Stress Testing:** AI systems must be rigorously stress-tested against corrupted, missing, or poisoned data (sensor drift, communication failures, and cyber-physical spoofing) to evaluate how well the model communicates data boundaries and maintains utility.
- **Physics-Based Accuracy & Edge-Case Validation:** Validation requires moving beyond average performance to test rare "corner cases" (e.g., extreme weather, 3-phase faults). Accuracy should be verified using telemetry data, physics-based models, and ensemble schemes (like Byzantine architectures) to confirm reality-aligned outputs.

Control Room of the Future Testbed Workshop

Topic C: Available Testbeds and Future Needs *Findings*

- **Data Fabric Prerequisites & Sharing Friction:** Reliable data infrastructure (such as a unified data lake or data fabric) must precede testbed development. Overcoming institutional hurdles, including NDA and data-sharing bottlenecks, requires adopting Privacy Preserving Federated Learning (PPFL) to safely bridge visibility gaps at the grid edge.
- **Human-AI Co-Validation & Seamless UI:** Testbeds must feature human-in-the-loop capabilities to compare human and AI outcomes under identical scenarios. To build operator trust and prevent adoption fatigue, AI tools must integrate into existing, familiar user interfaces rather than forcing operators onto separate applications.
- **Holistic, Modular, and Adaptive Architecture:** Conventional validation cannot handle rapid AI evolution and grid complexity. Future testbeds require a modular, "plug-and-play" framework to evaluate cross-tool dependencies, preventing local AI solutions from causing unintended, negative knock-on effects elsewhere in the control room.
- **Adversarial Cybersecurity & Business Case Proofs:** Testbeds must evolve to counter AI-specific threats (such as prompt injection, model drift, hallucination risks, and workflow hijacking) while aligning with NERC CIP compliance. The platform must quantify real economic value and reduced operational costs to justify utility adoption.

Control Room of the Future Testbed Workshop

Conclusions

- **Holistic Grid Modernization:** Control room evolution is a systems-level transformation, not a simple software upgrade, requiring coordinated alignment across technology, workforce capability, regulation, and culture.
- **Human-Centered AI Integration:** While AI is essential to manage growing grid complexity, widespread adoption depends on human-in-the-loop implementation and rigorous validation frameworks that build operator trust.

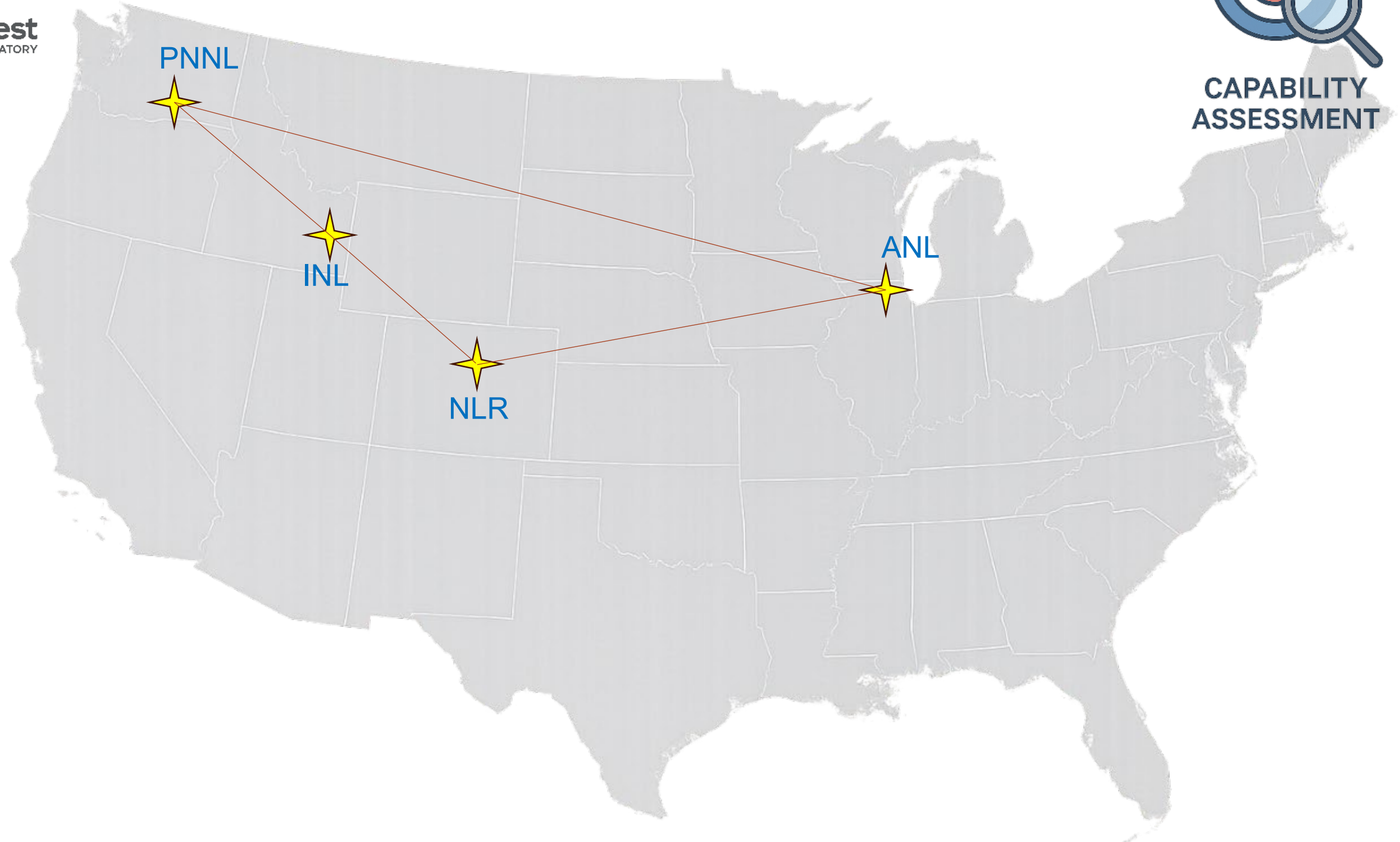
Next Steps

- **Functional & Integration Mapping:** Findings will define critical system integration points across legacy OT, field devices, and enterprise IT, prioritizing high-value use cases like simulation training and real-time decision support.
- **Hybrid Validation Workflows:** Captured requirements will guide the physical design of safe, hybrid simulation environments, ensuring emerging tools achieve institutional trust before influencing live grid decisions.
- **DOE Capability Gap Isolation:** Prioritized operational pain points (e.g., mitigating information overload) will be used to map the AI adoption landscape, isolating critical technical gaps that require federal funding and intervention.

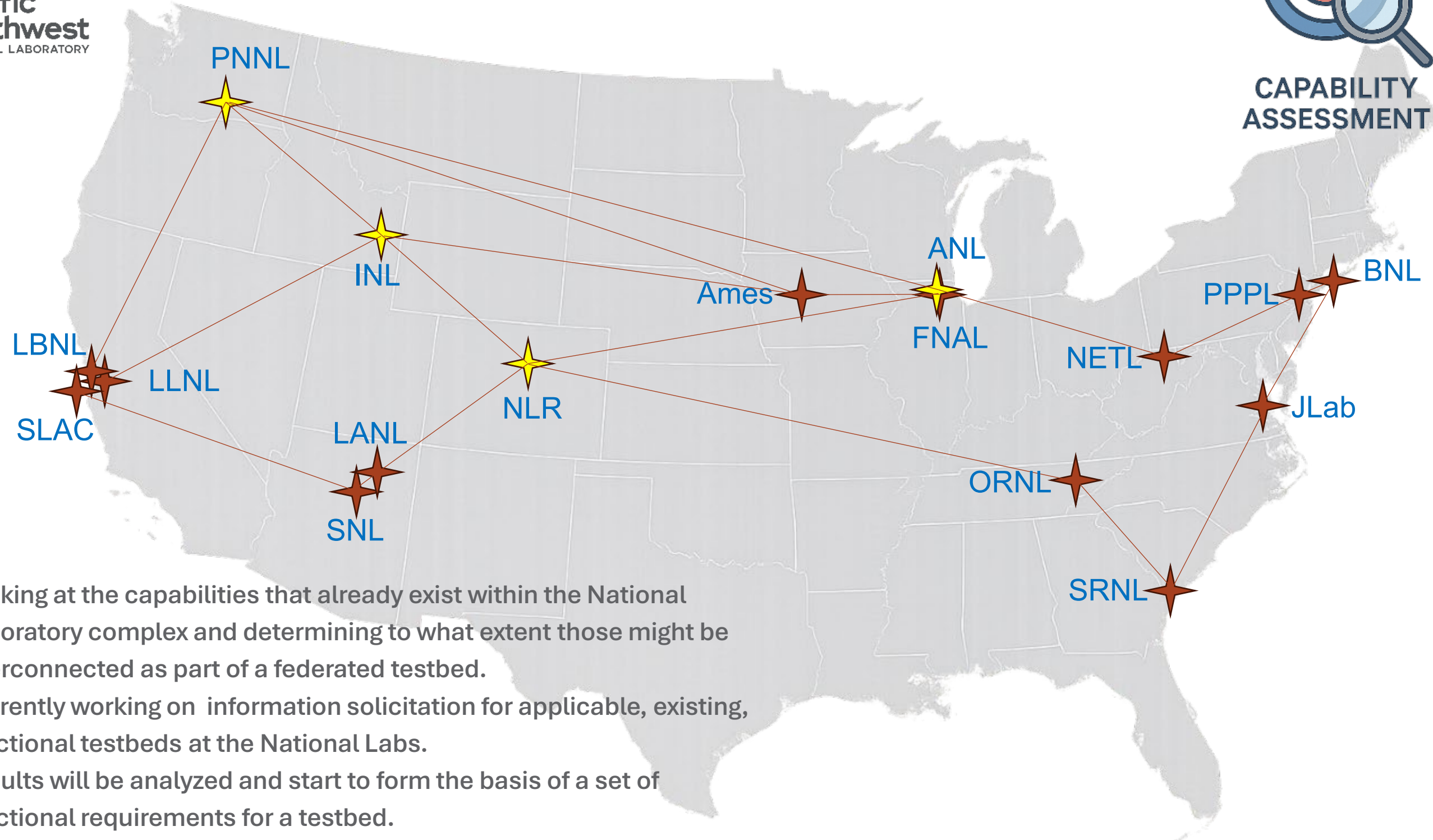
National Laboratory Testbed Assessment



CAPABILITY
ASSESSMENT



National Laboratory Testbed Assessment



- Looking at the capabilities that already exist within the National Laboratory complex and determining to what extent those might be interconnected as part of a federated testbed.
- Currently working on information solicitation for applicable, existing, functional testbeds at the National Labs.
- Results will be analyzed and start to form the basis of a set of functional requirements for a testbed.

CONTROL ROOM OF THE FUTURE TESTBED

Federated National Laboratory Testbed Architectural Taxonomy — Unified Architectural Layers

Argonne National Laboratory (ANL)
Idaho National Laboratory (INL)
National Laboratory of the Rockies (NLR)
Pacific Northwest National Laboratory (PNNL)

FUNCTIONAL LAYER

APPLICATIONS & EXAMPLES



Institutional & Governance

Agreements, bodies, business models, standards and policies that govern the operation and use of shared resources in a federated testbed while addressing safety and security requirements.

Defines the policy, legal, and organizational boundaries that govern multi-institution collaboration, safety mandates, AI and data-sharing governance, policy and regulatory frameworks, and operator authority; defines roles and responsibilities for operating the testbed(s).

This layer may include: Multi-lab MOUs and data-sharing frameworks • NERC CIP compliance frameworks • Cybersecurity boundary agreements • AI and data governance frameworks • Privacy and security baselines • Acceptable use policies (AUPs) • Zero-trust identity federation (TRUSTID) • Institutional Review Boards (IRBs) • Federated incident response protocols • Policy and Regulatory Standards • Technical Standards



Operational & Cognitive

Operational tools, technologies, approaches, and workflow studies in the control room, including humans-in-the-loop (operators), decision support and other applications of AI.

Encapsulates the decision-making logic, workflow automation, and AI-assisted control and operation functions that translate policy intent into real-time grid and facility operations.

This layer may include: EMS, WAMS, DMS, and DERMS for grid optimization • AI decision support and agents • Advanced analytics tools and engineering visualizations • Automated demand response orchestration • Reinforcement-learning dispatch agents • Contingency analysis tools • Human-in-the-loop override workflows • Explainability dashboards • Data historians • Situational awareness and supervisory control tools • Trust substrate for AI: provenance, evaluation and benchmarking sets



Semantic & Informational

Data pipeline with both real and synthetic data and shared data models, ontologies, and exchange schemas.

Ensures that all federated nodes interpret and communicate information with a common meaning across different workflows and tools.

This layer may include: Public and proprietary data sets • IEC 61968/61970 Common Information Model (CIM) • Federated metadata catalogs • Time-series historian schemas (e.g., PI/InfluxDB) • Dataset registries • Cloud infrastructure such as scalable cloud storage (e.g., AWS, Azure) • Cross-lab data exchange • Dynamic model validation • Privacy-preserving federated learning gradient schemas • AI training compute substrate • DOE exascale HPC resources (e.g., ALCF, OLCF, NERSC)



Communication & Transport

Digital communication networks and transport protocols for grid communication simulation and testbed configuration, interface controls, interoperability, and federation.

Establishes the networking communication infrastructure and protocols, message brokers, and data transport fabric that move telemetry, control signals, and simulation state between testbed layers and federated nodes.

This layer may include: Network simulators (e.g., NS-3) • Wired/wireless/cellular/radio communication infrastructure (e.g., WAN, LAN, HAN, 5G, LTE) • ESnet6 optical backbone • EJFAT FPGA load balancers • Communication tools/brokers (e.g., HELICS communication brokers) • Network switches • Phasor data concentrators • Precision time servers • Communication gateways and communication protocols (e.g., OpenADR 3.0, IEEE C37.118 synchrophasor streaming, IEC 61850 substation messaging, OpenFMB device communication, DNP3 and Modbus)



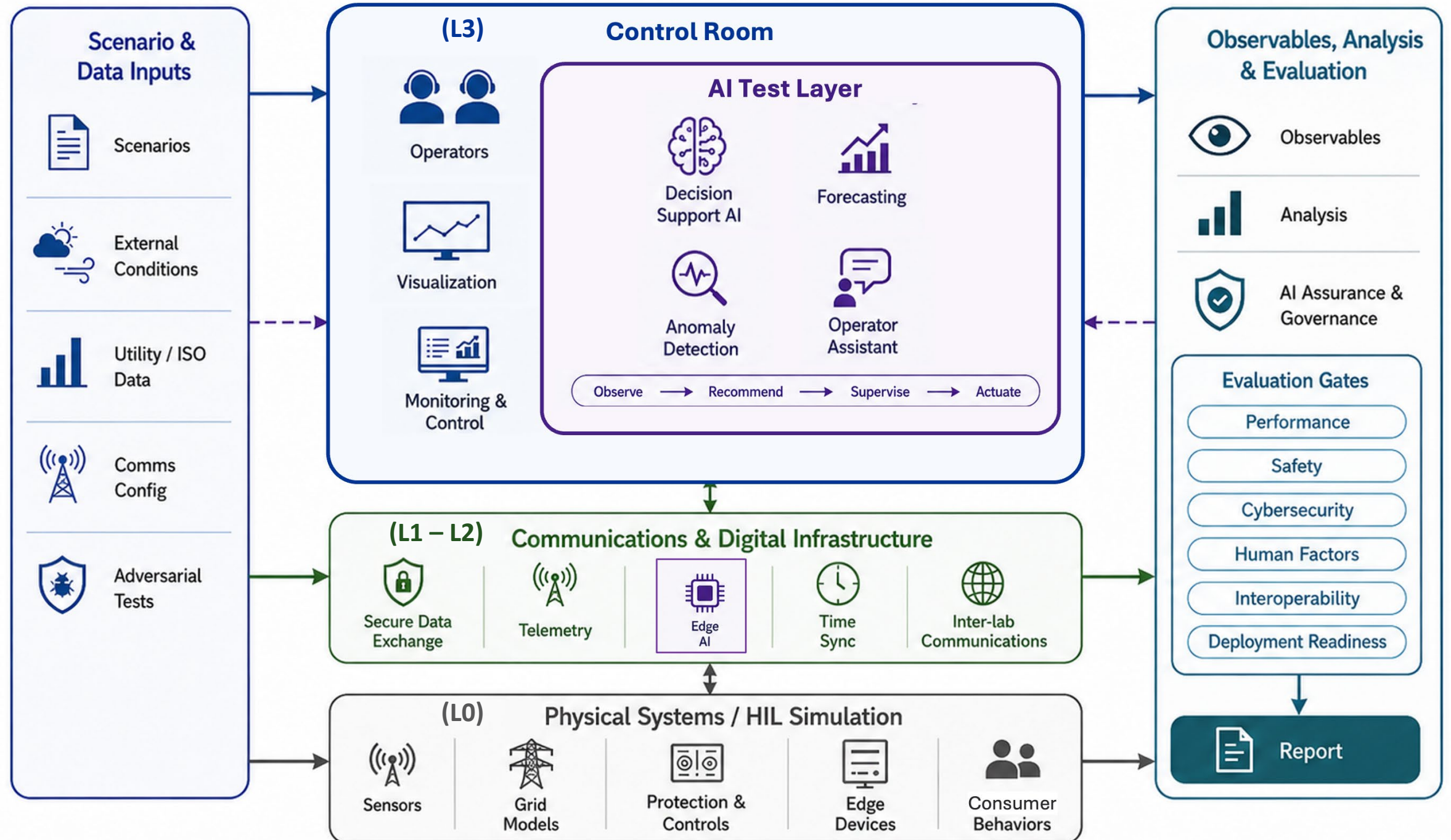
Physical & Simulation

All interconnected physical hardware assets, grid simulation tools, sensors, and supporting testbed infrastructure.

Represents the power system to be controlled and provides data to other layers through hardware or simulated sensors. This is an emulation of the real grid and grid dynamics are represented with different levels of fidelity.

This layer may include: Real-time and non-real-time simulators • Tangible hardware assets for generation and storage (e.g., PV, battery and fuel cell emulators and inverters; diesel generators) and loads (e.g., EVs, heat pumps, water heaters) • Automation controllers (e.g., substation controllers, microgrid controllers, AMI 2.0 and AI edge controllers) • Sensors and protection devices • Remote terminal units (RTUs) and phasor measurement units (PMUs) • Lab equipment such as AC and DC power amplifiers and digital-to-analog converters for HIL coupling

Control Room of the Future Testbed Architecture



High Level Conclusions

To summarize the key messages from what we've learned so far:

- 1. The grid is becoming increasingly difficult to manage**
- 2. Data serves as both a challenge and solution**
- 3. AI and automation show promise, but trustworthiness must be established**
- 4. Validation and testing are not keeping pace with innovation**
- 5. Workforce and institutional readiness are critical gaps**
- 6. A control room testbed must have sufficient modularity, scalability, flexibility, and fidelity, to test and evaluate new tools, technologies, approaches, and architectures.**



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2006
TO
2026



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**WEBINAR
SERIES
2026**

Next Webinar!

Transactive Energy

August 12, 2026

10:00 – 11:00 am PDT

<https://www.pnnl.gov/projects/eioc/webinar-series>



Hayden Reeve

Thank you

